**Convection in the oceans and mantle-** *with answers*

Objectives: Upon completion of this activity, you should be able to:

* Describe how energy drives movement and change in the hydrosphere and mantle. You should also be able to predict how circulation in the hydrosphere and asthensophere may change due to different thermal conditions.

The Causal Principles addressed in this activity are:

1. Gravitational energy, thermal energy and/or chemical **energy** drive all movement and change of matter on Earth.

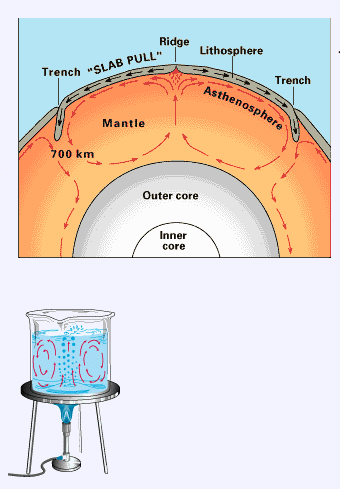
3. Matter moves and changes to return a system to **equilibrium**.

1. **Temperature** is a measure of the movement of molecules. Higher temperature means molecules are moving faster.
2. When molecules move faster, the **density** of most substances decreases. Water is an anomaly because liquid water is more dense than ice.
3. **Buoyancy** causes materials to rise or fall due to the relative density of materials.

**1. Description of movement in the mantle and lithosphere**

The following is from the readings for lesson 14 (<http://pubs.usgs.gov/gip/dynamic/unanswered.html>)

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The mobile rock beneath the rigid plates is believed to be moving in a circular manner somewhat like a pot of thick soup when heated to boiling. The heated soup rises to the surface, spreads and begins to cool

and then sinks back to the bottom of the pot where it is reheated and rises again. This cycle is repeated over and over to generate what scientists call a *convection cell* or *convective flow.* While convective flow can be observed easily in a pot of boiling soup, the idea of such a process stirring up the Earth's interior is much more difficult to grasp. While we know that convective motion in the Earth is much, much slower than that of boiling soup, many unanswered questions remain: How many convection cells exist? Where and how do they originate? What is their structure?

Convection cannot take place without a source of heat. Heat within the Earth comes from two main sources: *radioactive decay* and *residual heat.* Radioactive decay, a spontaneous process that is the basis of "isotopic clocks" used to date rocks, involves the loss of particles from the nucleus of an isotope (the *parent*) to form an isotope of a new element (the *daughter*). The radioactive decay of naturally occurring chemical elements -- most notably uranium, thorium, and potassium -- releases energy in the form of heat, which slowly migrates toward the Earth's surface. Residual heat is gravitational energy left over from the formation of the Earth -- 4.6 billion years ago -- by the "falling together" and compression of cosmic debris. How and why the escape of interior heat becomes concentrated in certain regions to form convection cells remains a mystery.

Until the 1990s, prevailing explanations about what drives plate tectonics have emphasized mantle convection, and most earth scientists believed that seafloor spreading was the primary mechanism. Cold, denser material convects downward and hotter, less dense material rises because of gravity; this movement of material is an essential part of convection. In addition to the convective forces, some geologists argue that the intrusion of magma into the spreading ridge provides an additional force (called "ridge push") to propel and maintain plate movement. Thus, subduction processes are considered to be secondary, a logical but largely passive consequence of seafloor spreading. In recent years however, the tide has turned. Most scientists now favor the notion that forces associated with subduction are more important than seafloor spreading. Professor Seiya Uyeda (Tokai University, Japan), a world-renowned expert in plate tectonics, concluded in his keynote address at a major scientific conference on subduction processes in June 1994 that "subduction . . . plays a more fundamental role than seafloor spreading in shaping the earth's surface features" and "running the plate tectonic machinery." The gravity-controlled sinking of a cold, denser oceanic slab into the subduction zone (called "slab pull") -- dragging the rest of the plate along with it -- is now considered to be the driving force of plate tectonics”.

Slab pull occurs because oceanic lithosphere slowly cools as it moves away from a spreading ridge. This gradual cooling causes the oceanic lithosphere to become denser. Eventually, it becomes denser than the underlying mantle and begins to sink. Subduction zones are zones where the oceanic lithosphere is sinking.

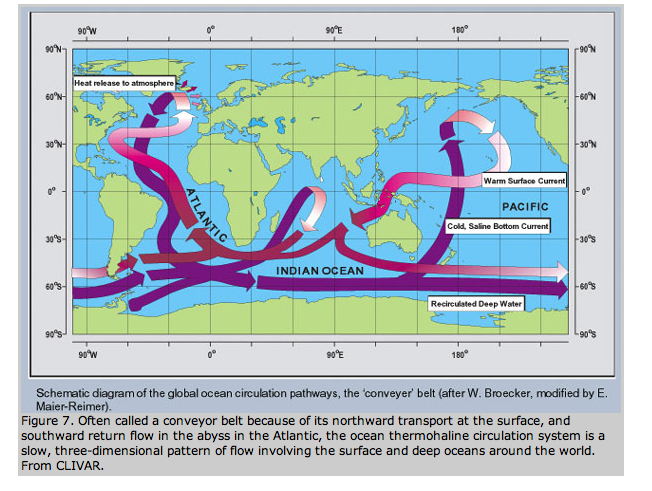
In some ways, circulation in mantle is analogous to thermohaline circulation. As a review of theromohaline circulation, read the following two paragraphs from Chapter 3 in lesson 7. If you do not remember lesson 7, you may need to go back and review the lesson before attempting to complete this exercise.

**2. Description of thermohaline circulation**

The principles behind the global circulation of deep ocean water in the oceans is the same the circulation of air in the atmosphere. This circulation is called convection.

Convection occurs when a less dense fluid is underneath a denser fluid, causing a gravitational instability. In the atmosphere, air is hottest at the earth's surface because solar radiation absorbed by the surface is radiated back into the atmosphere at wavelengths that readily interact with molecules of gases in the atmosphere. This phenomenon is easily observed on a sunny day by placing your hand near the ground surface and feeling the heat radiating from the ground. The atmosphere cools with increasing elevation because the gravitational attraction between the earth and gas molecules in the atmosphere decreases with distance. This decrease in gravitational attraction causes the average distance between gas molecules to increase resulting in fewer molecular collisions and, therefore, lower temperature. As the air cools, it's density will increase and it will begin to sink toward the ground where reheating will cause if to rise again, completing the convection cycle.

This figure is from the NOAA website.



Oceans, on the other hand, are heated from above, not from below, so how might they convect? Sir Thompson figured out part of the answer. As wind driven currents move masses of water toward the poles, the water cools and becomes denser. Why does it cool? Because the solar radiation at the poles is less direct than at the equator. Surface waters also evaporate removing water molecules but leaves behind the dissolved matter. The water becomes saltier. In addition, when sea ice forms, water molecules freeze but most of the dissolved salt remains in the water. Both the decrease in temperature and the increase concentration of dissolved matter in the water makes the ocean water denser as it moves north. Eventually the water becomes dense enough to sink in the North Atlantic. But how does it rise again? What we've described so far suggests a mechanism to accumulate cold, salty bottom waters. These cold, salty bottom waters must be mixed with less salty and warmer waters before they can rise to the surface again and this mixing occurs by currents and smaller scale convections that occur through out the oceans.

***Part A. Alignment of features and relationships***

Movement in the mantle and lithosphere is analogous to thermohaline circulation. That is, many elements and relationships correspond. They correspond because they can be explained by the same causal principles or play the same roles in the causal processes. Before aligning the mantle and lithosphere with thermohaline circulation (Table3), place each the elements of mantle & lithosphere (Table 1) and the elements of thermohaline circulation (Table2) in correspondance with their explanatory causal principles/roles.

Table 1

|  |  |
| --- | --- |
| **Mantle and lithosphere** | **Causal Principle** |
| less dense material rises | *Buoyancy causes materials to rise or fall due to the relative density of materials* |
| cold, denser material convects downward | *Buoyancy causes materials to rise or fall due to the relative density of materials* |
| radioactive decay and residual heat | *Temperature is a measure of the movement of molecules. Higher temperature means molecules are moving faster.*  *When molecules move faster, the density of most substances decreases* |
| sinking lithosphere pulls lithosphere toward subduction zone | *Gravitational energy drives movement* |
| oceanic lithosphere slowly cools | *Matter changes to return to equilibrium* |

Table 2

|  |  |
| --- | --- |
| **Thermohaline Circulation** | **Causal Principles** |
| wind driven currents move masses of water toward the poles | *Gravitational energy drives movement* |
| mixing of cold bottom waters and warmer surface waters | *Gravitational energy drives movement* |
| solar radiation at the poles is less direct than at the equator | *Temperature is a measure of the movement of molecules. Higher temperature means molecules are moving faster.*  *When molecules move faster, the density of most substances decreases* |
| The water becomes saltier | *Buoyancy causes materials to rise or fall due to the relative density of materials* |
| the water becomes dense enough to sink in the North Atlantic | *Buoyancy causes materials to rise or fall due to the relative density of materials* |

In table 3, we will align elements of the mantle and lithosphere that affect convection with elements of oceans and atmsophere that weffect theromhaline circulation. Complete table 3 by listing ellements of the ocean and causal principles that align with the listed ellements of the mantle and lithosphere. Because some of the principles are directly realted to others, the principle you cite for an element in table 3 can be different from a principle you cited for that element in tables 1 or 2.

Table 3

|  |  |  |
| --- | --- | --- |
| **Mantle and lithosphere** | **Thermohaline** | **Causal Principle** |
| less dense material rises | *mixing of cold bottom waters and warmer surface waters* | *Buoyancy causes materials to rise or fall due to the relative density of materials* |
| cold, denser material convects downward | *the water becomes dense enough to sink in the North Atlantic* | *Buoyancy causes materials to rise or fall due to the relative density of materials* |
| radioactive decay and residual heat | *solar radiation at the poles is less direct than at the equator* | *Temperature is a measure of the movement of molecules. Higher temperature means molecules are moving faster.*  *When molecules move faster, the density of most substances decreases.* |
| sinking lithosphere pulls lithosphere toward subduction zone | *wind driven currents move masses of water toward the poles* | *Gravitational energy drives movement* |
| oceanic lithosphere slowly cools | *The water becomes saltier* | *Buoyancy causes materials to rise or fall due to the relative density of materials* |

Part B. Important Alignable Differences between Thermohaline Circulation & Movement in the Mantle and Lithosphere.

Making Analogies isn’t just about finding what’s similar between two domains, but also discovering and understanding important differences. Briefly discuss why the following two differences between the mantle and llithosphere compared to oceans result from differences in what drives convection and how different materials respond to these driving forces.

1) The oceans are heated from above but the mantle is heated from within and, particularly heated near the core mantle boundary.

*The fact that ocenas are not heated from below means other forces must allow the cold dense bottom waters to rise in order to complete the convection. Wind driven currents mix the cold bottom waters with warmer surface waters allowing the bottom waters to rise*.

2) The mantle may flow at rates of a few inches per year while ocean water may flow a few inches in less than a minute.

*The mantle is solid but can slowly flow because it is hot. Liqid ocean water can, of course flow easily.*

***Part C. Inference***

Analogies help us make inferences. In this exercise, we hope the analogies between soup (mentioned in the reading above), the mantle and lithosphere cycling, and thermohaline circulation provide you with a better understanding of the mechanism of movement in the oceans and solid earth. As a test of this understanding, please answer the following question.

Question: Was slab pull an important mechanism for moving tectonic plates 3 billion years ago? Here’s some relevant information.

Three billion years ago the earth’s interior was hotter than today because there was more radioactive material and because there was more of the original heat from the gravitational energy released during the formation of the earth 4.6 billion years ago. Also, there were areas of oceanic lithosphere and continental lithosphere three billion years ago. Geologists have evidence that the amount of continental lithosphere was less than it is today. They also have evidence that the chemical composition of the oceanic and continental lithosphere were about the same as they are today.

Explain your reasoning.

*Slab pull was problably important 3 billion years ago but convection may have been even more important because, with a hotter interior, the density difference between the hot lower mantle and cooler upper mantle may have been greater. If the oceanic lithosphere was a cool 3 billion years aga as it is today but the mantle hotter, then the mantel may have been less dense. This would increase the rate of slab pull makin it more important 3 billion years ago.*

Assessment:

1) Why does oceanic lithosphere subduct and continental lithosphere not subduct?

*Continental lithosphere does not subduct becaue it is less dense than the mantle. Cold oceanic lithosphere is more dense than the mantle.*

2) Why is older oceanic lithosphere more likely to subduct than younger oceanic lithosphere?

*After oceanic lithosphere forms at a mid-ocean ridge, it slowly cools. As it cools, it becomes denser. Therefore, old oceanic lithosphere is more dense than young oceanic lithosphere. The older, more dense lithosphere can subduct beneath younger, less dense lithosphere.*